TerraPower Overview

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NES APS-AAPT-SPS Meeting Plenary

University of Massachusetts Amherst

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TerraPower™

It all began with…

TerraPower

TerraPower Mission

To develop and commercialize the Traveling Wave Reactor (TWR) nuclear power technology which will:

- Minimize energy costs
- Assure availability of energy to all nations
- Maximize inherent proliferation resistance
- Offer new options for nuclear waste
- Improved safety essential in all options

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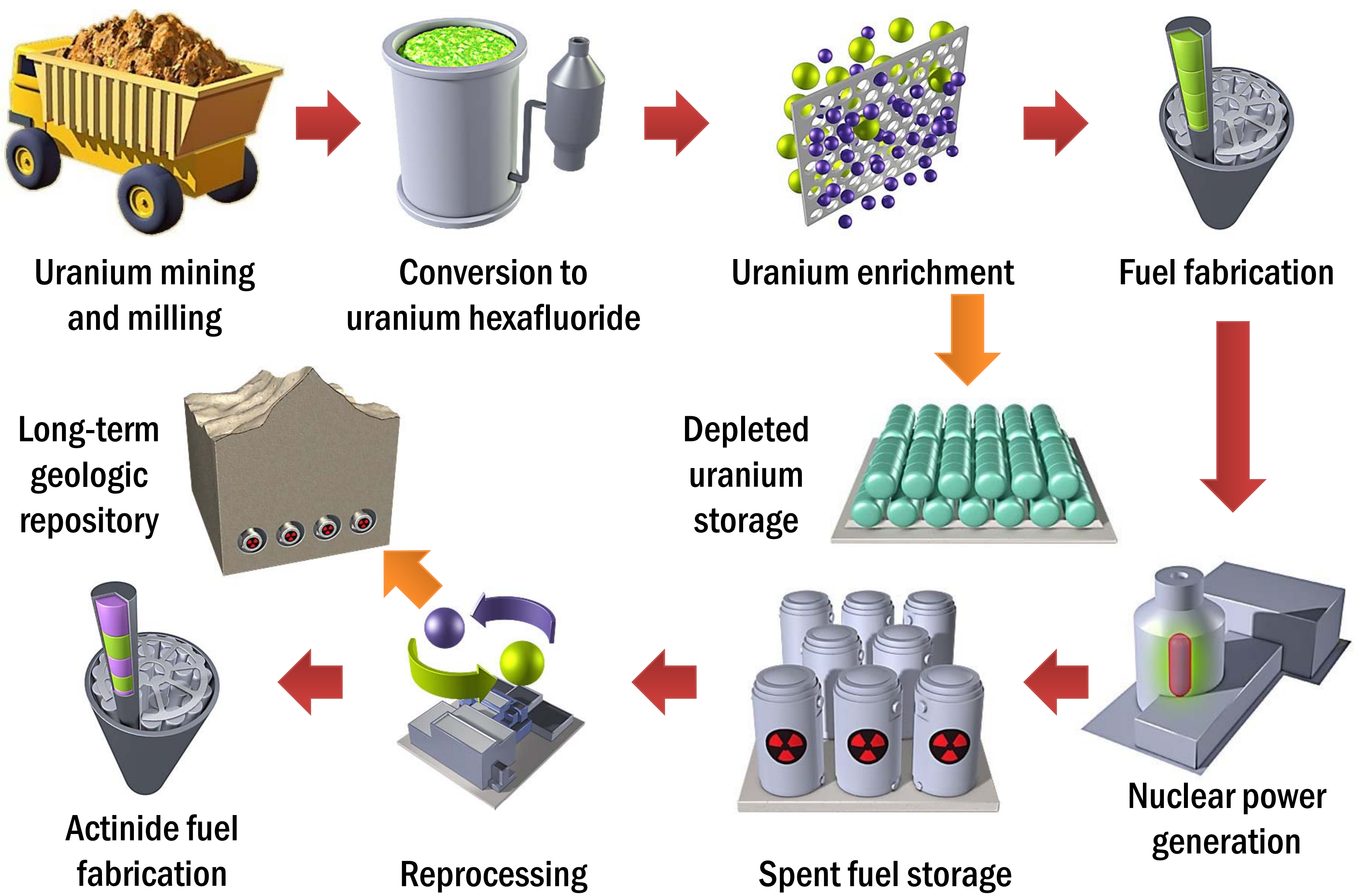
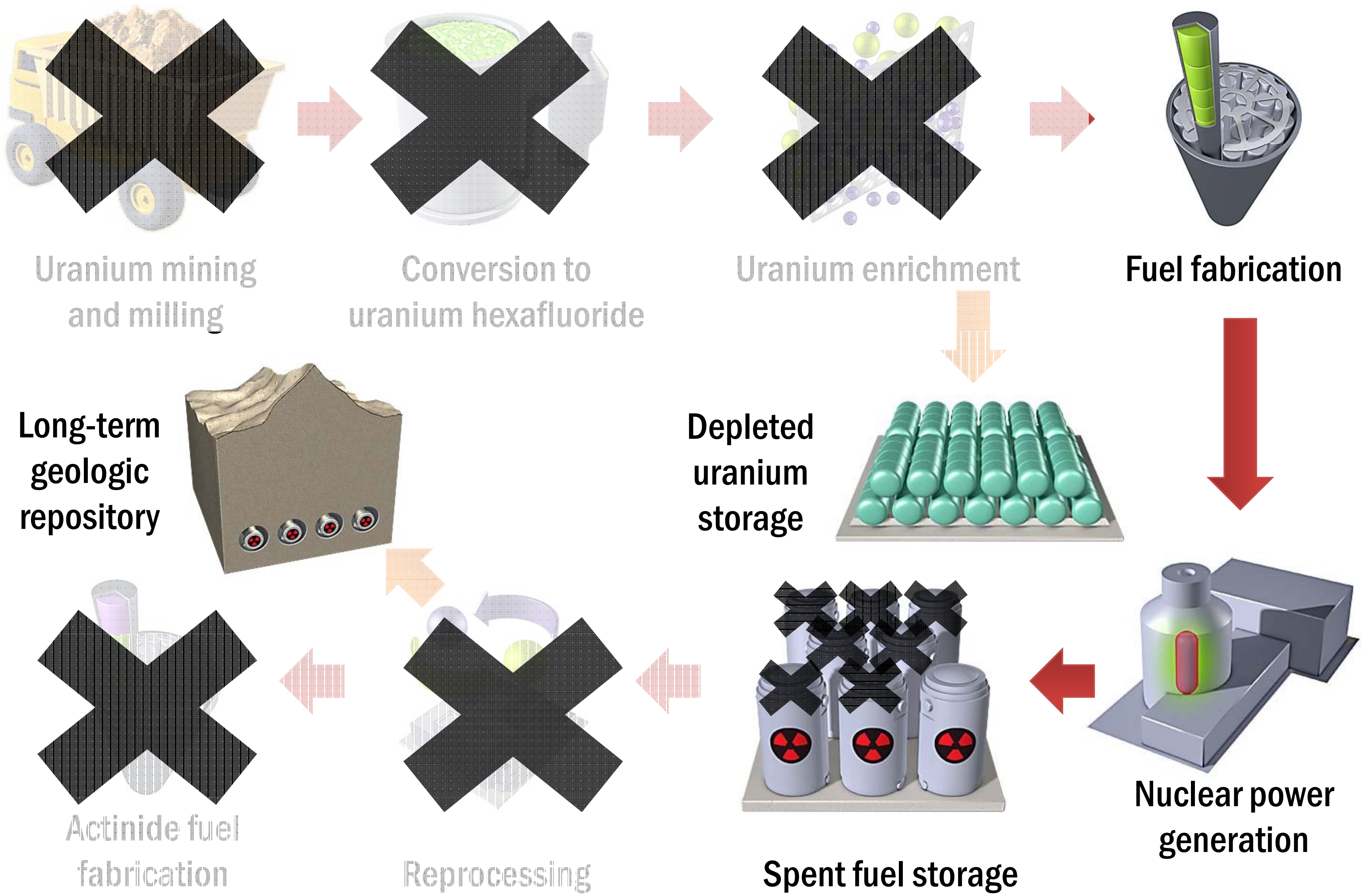
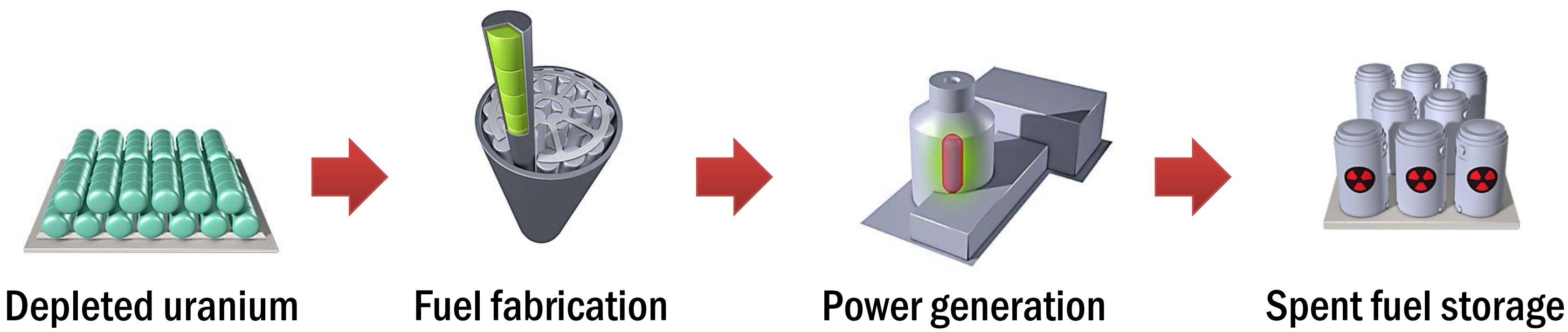
Current Nuclear Energy System



TWR Nuclear Energy System



TWR Results in a Cleaner, Safer Fuel Cycle



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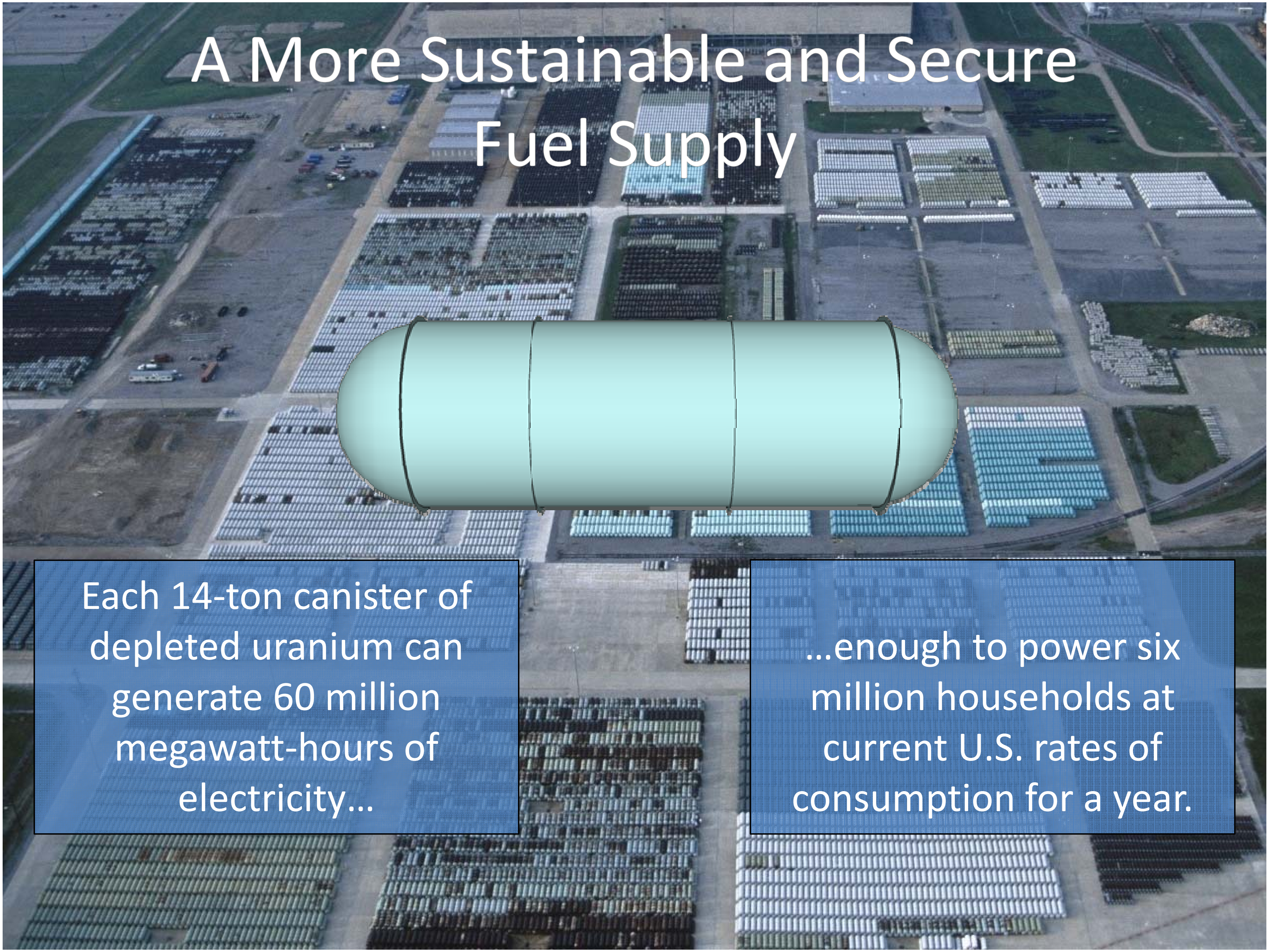
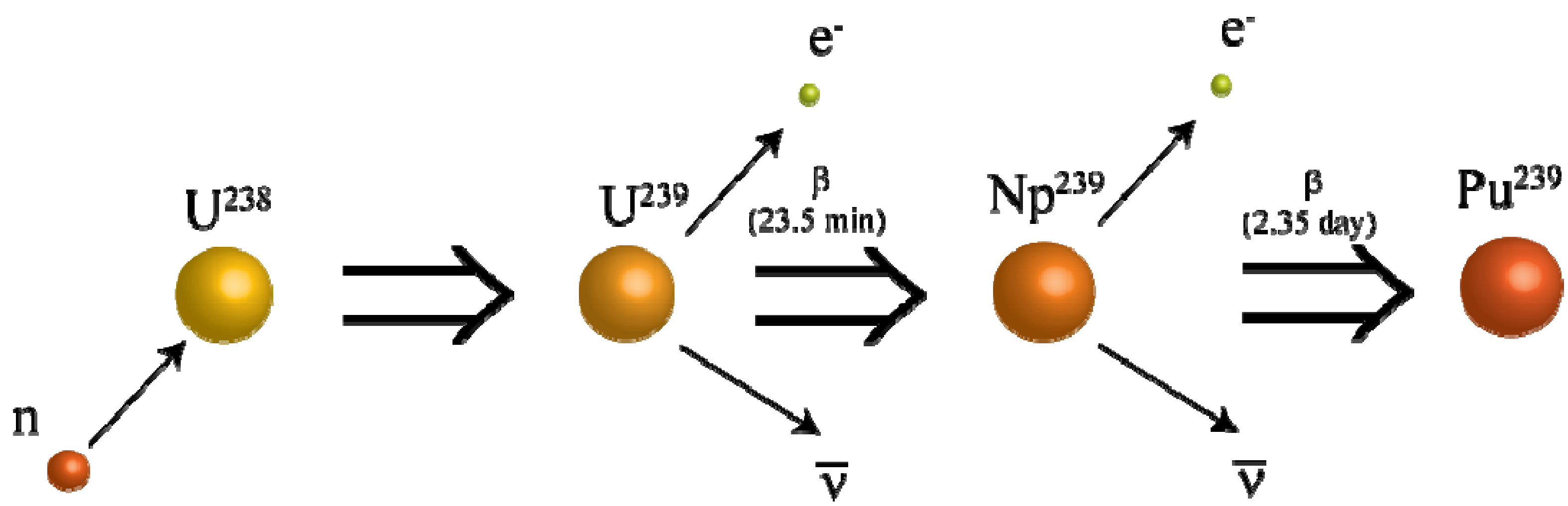

A More Sustainable and Secure Fuel Supply
Each 14-ton canister of depleted uranium can generate 60 million megawatt-hours of electricity…
…enough to power six million households at current U.S. rates of consumption for a year.

Fundamental Physics of a TWR



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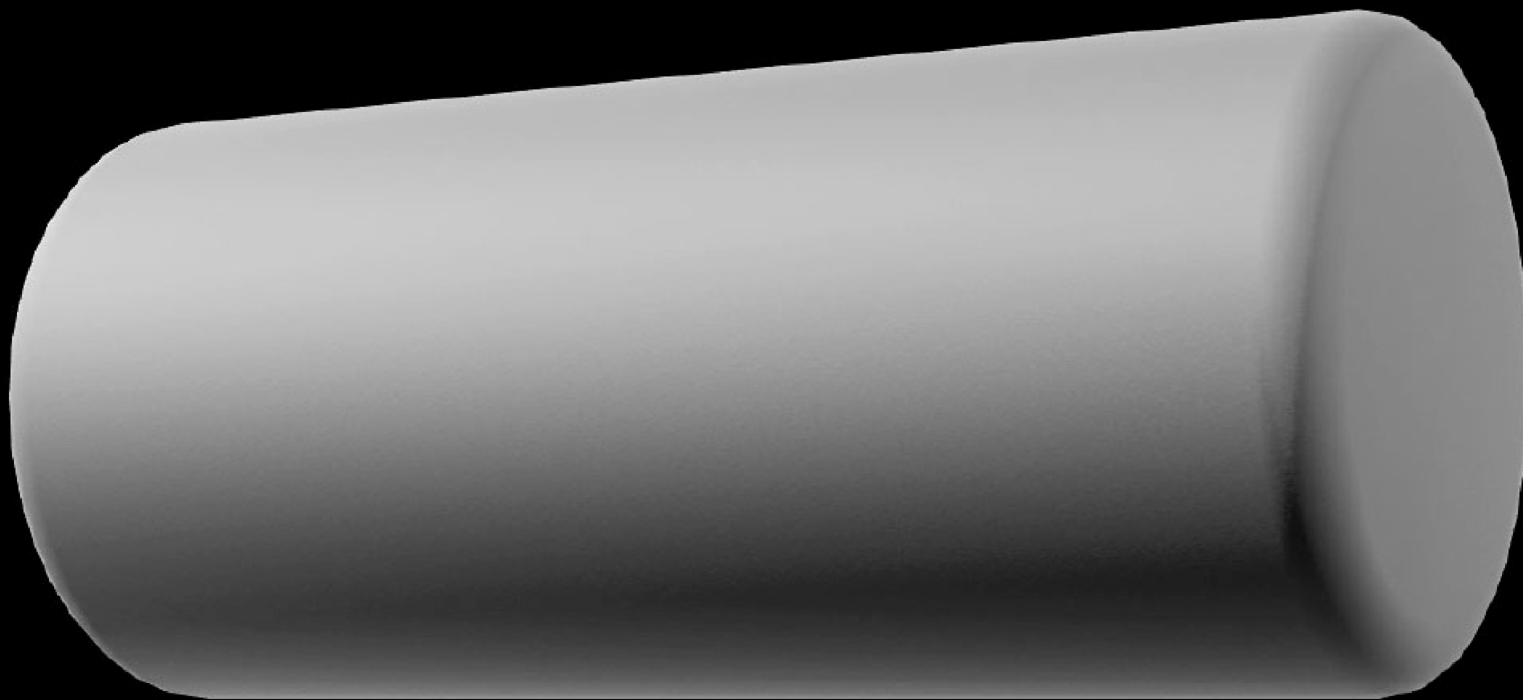
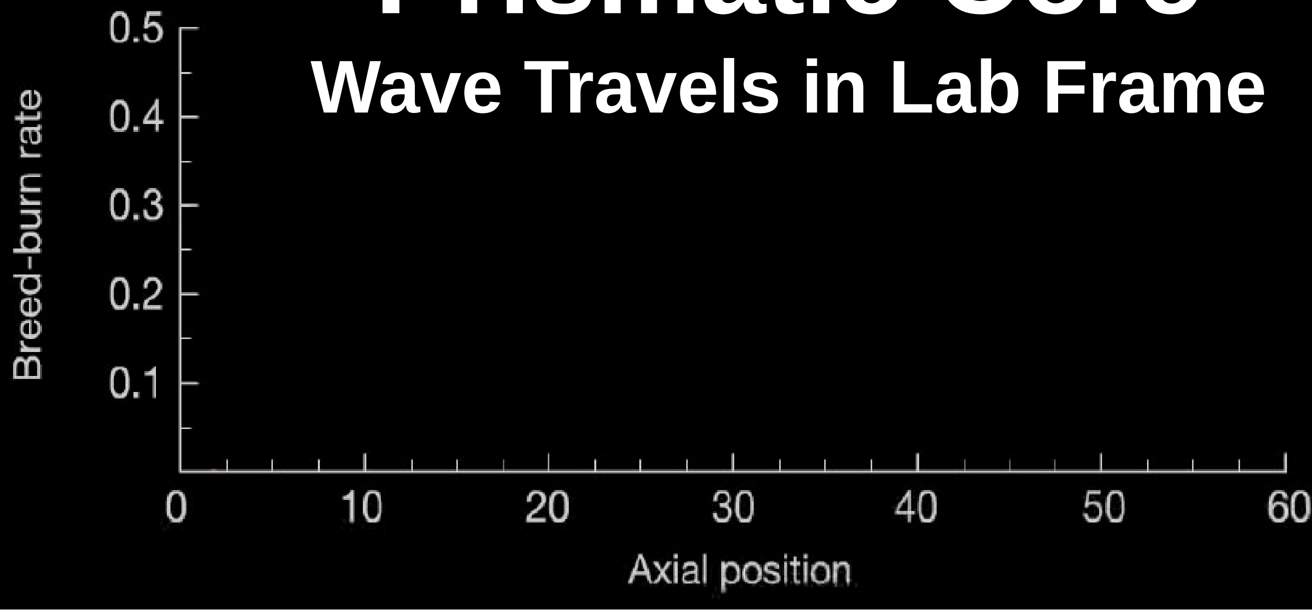
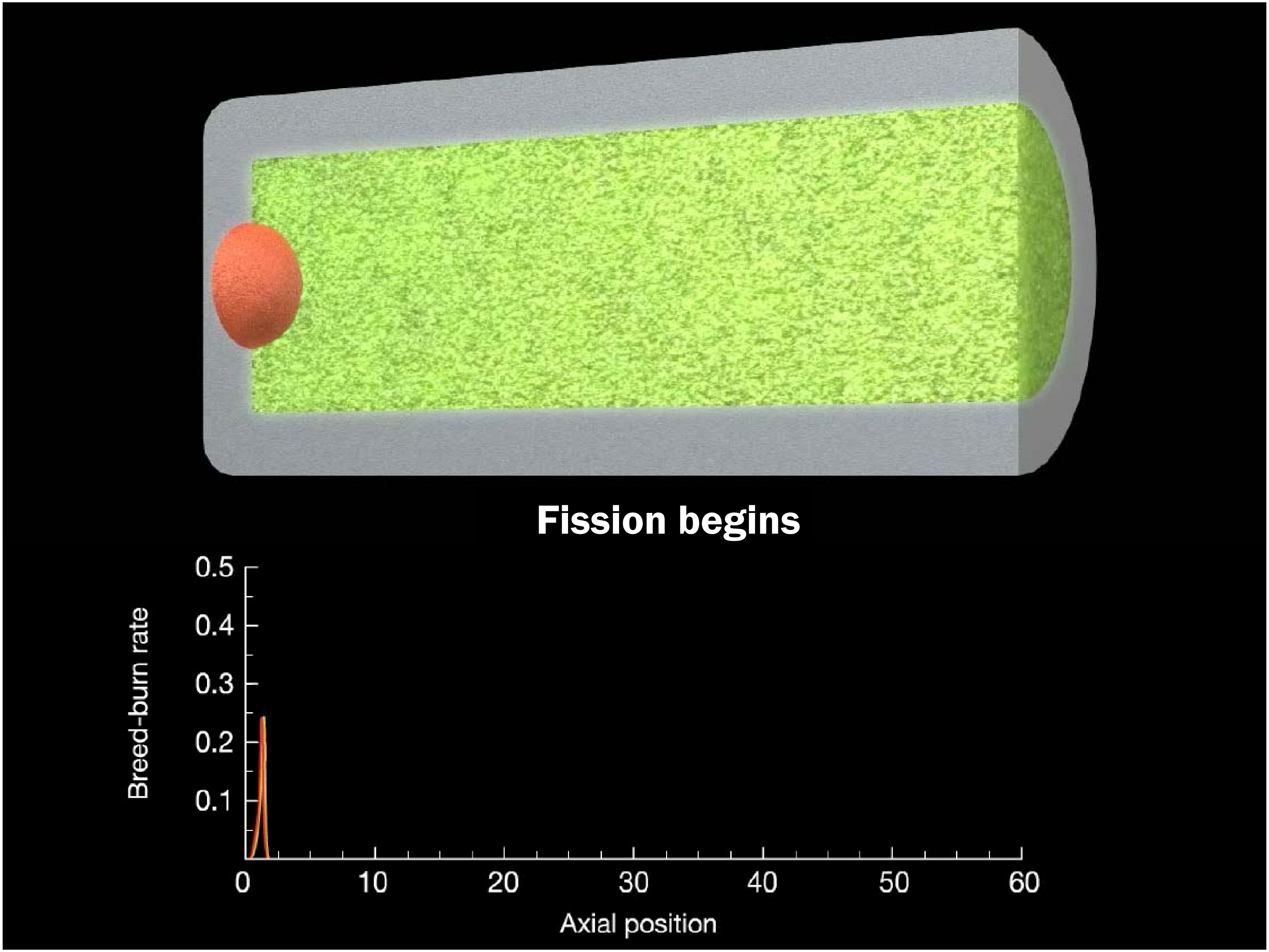
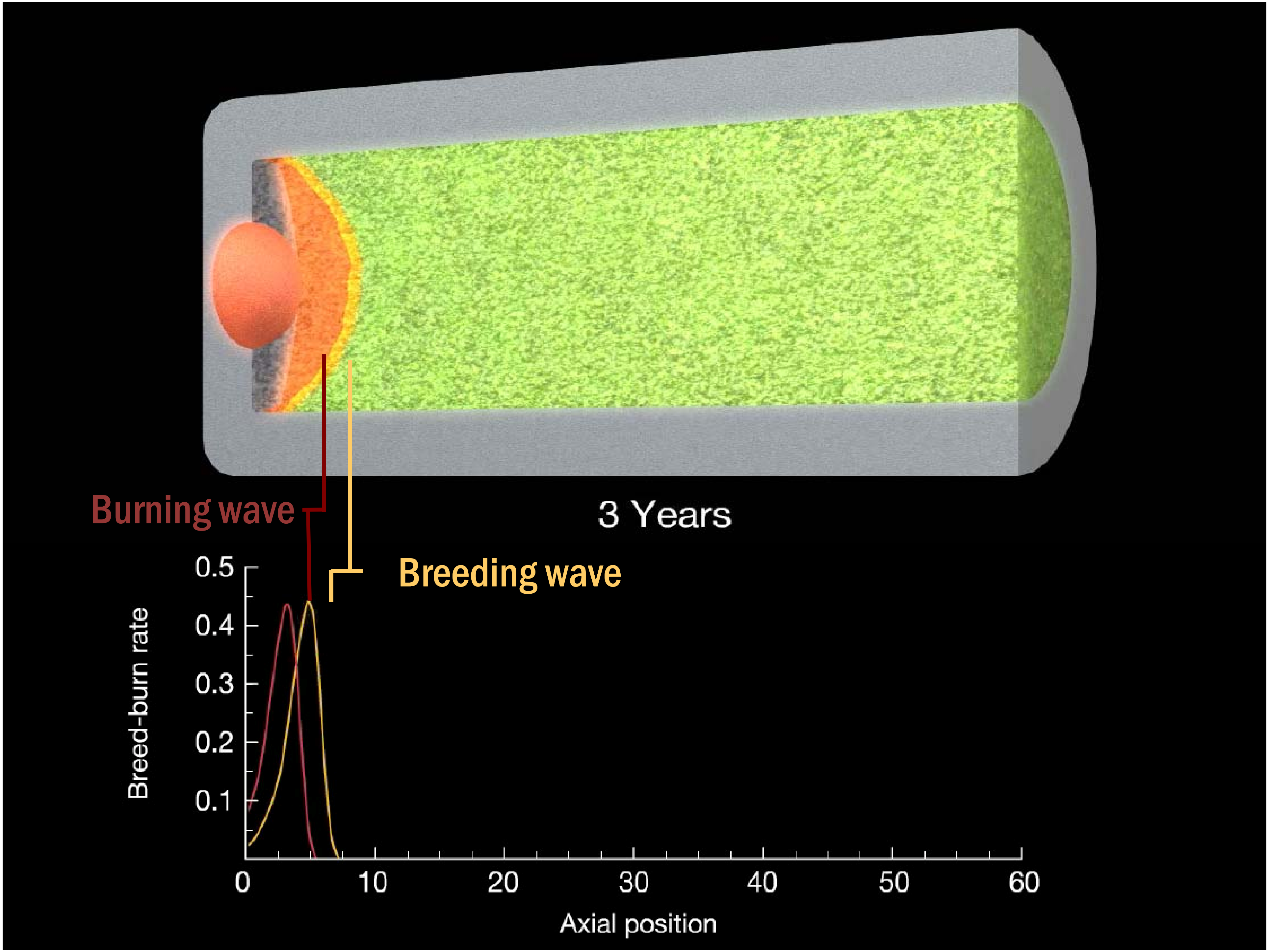


Prismatic Core

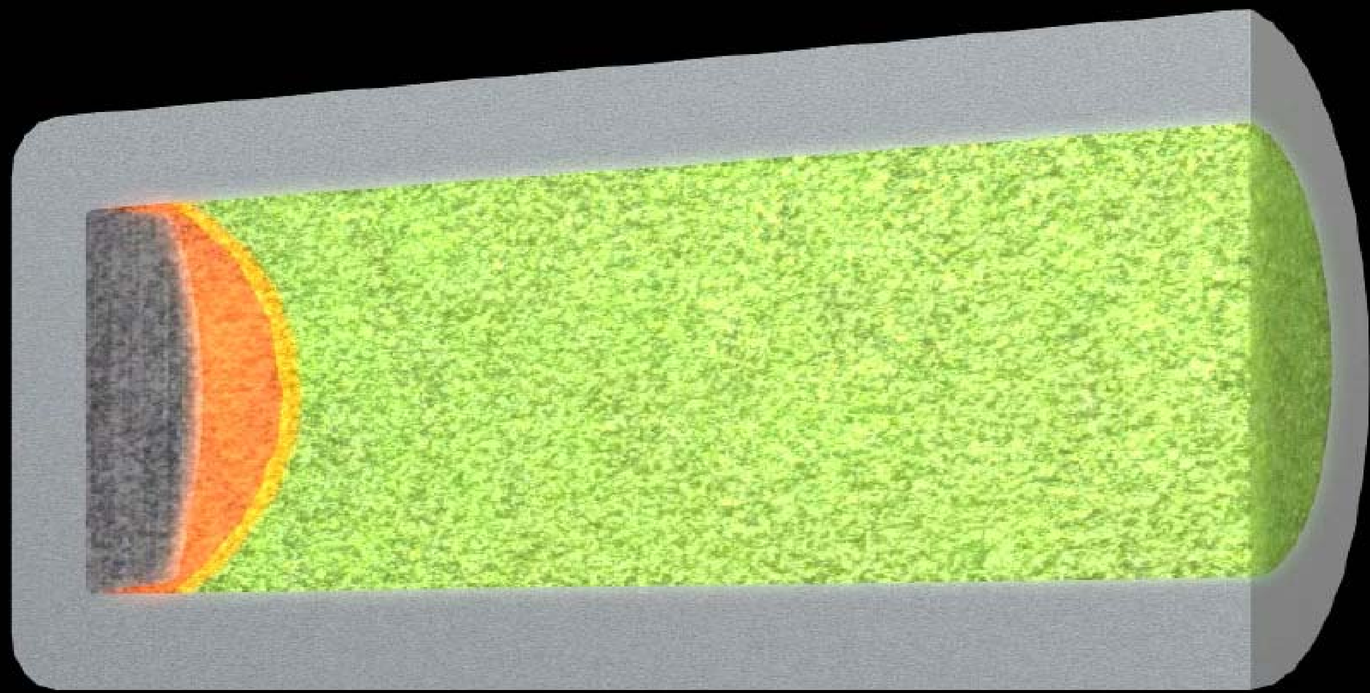
Wave Travels in Lab Frame



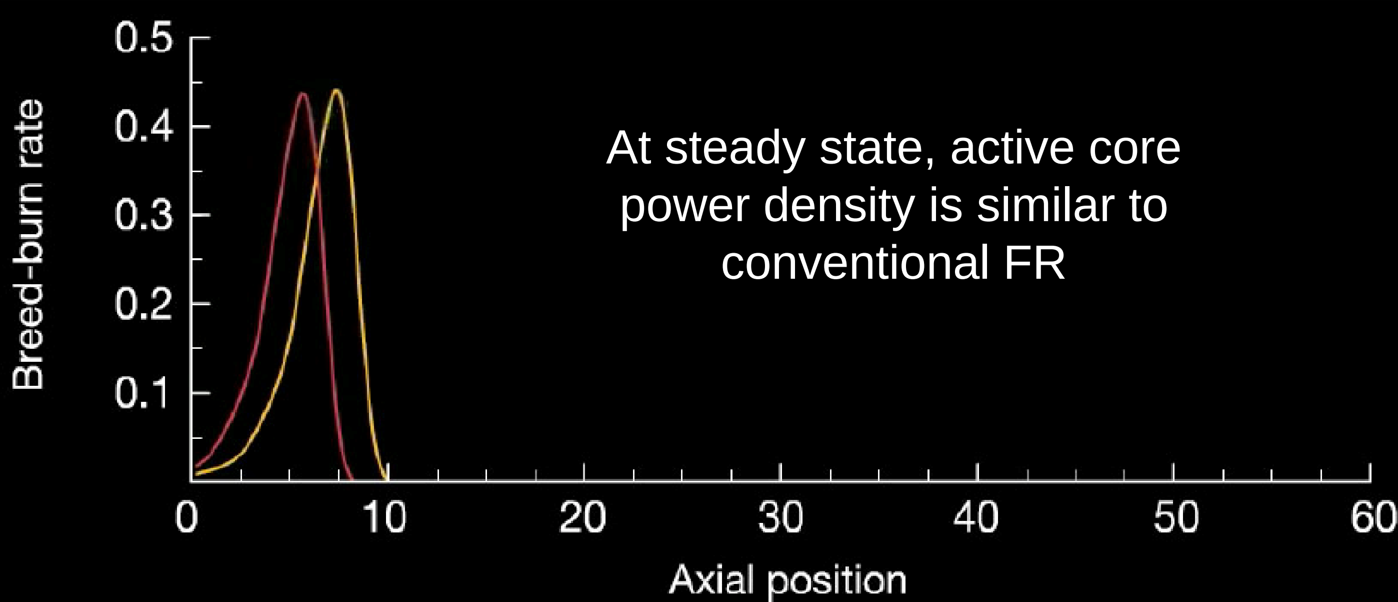

Fission begins
Breed-burn rate
0.5
0.4
0.3
0.2
0.1
0
10
20
30
40
50
60
Axial position



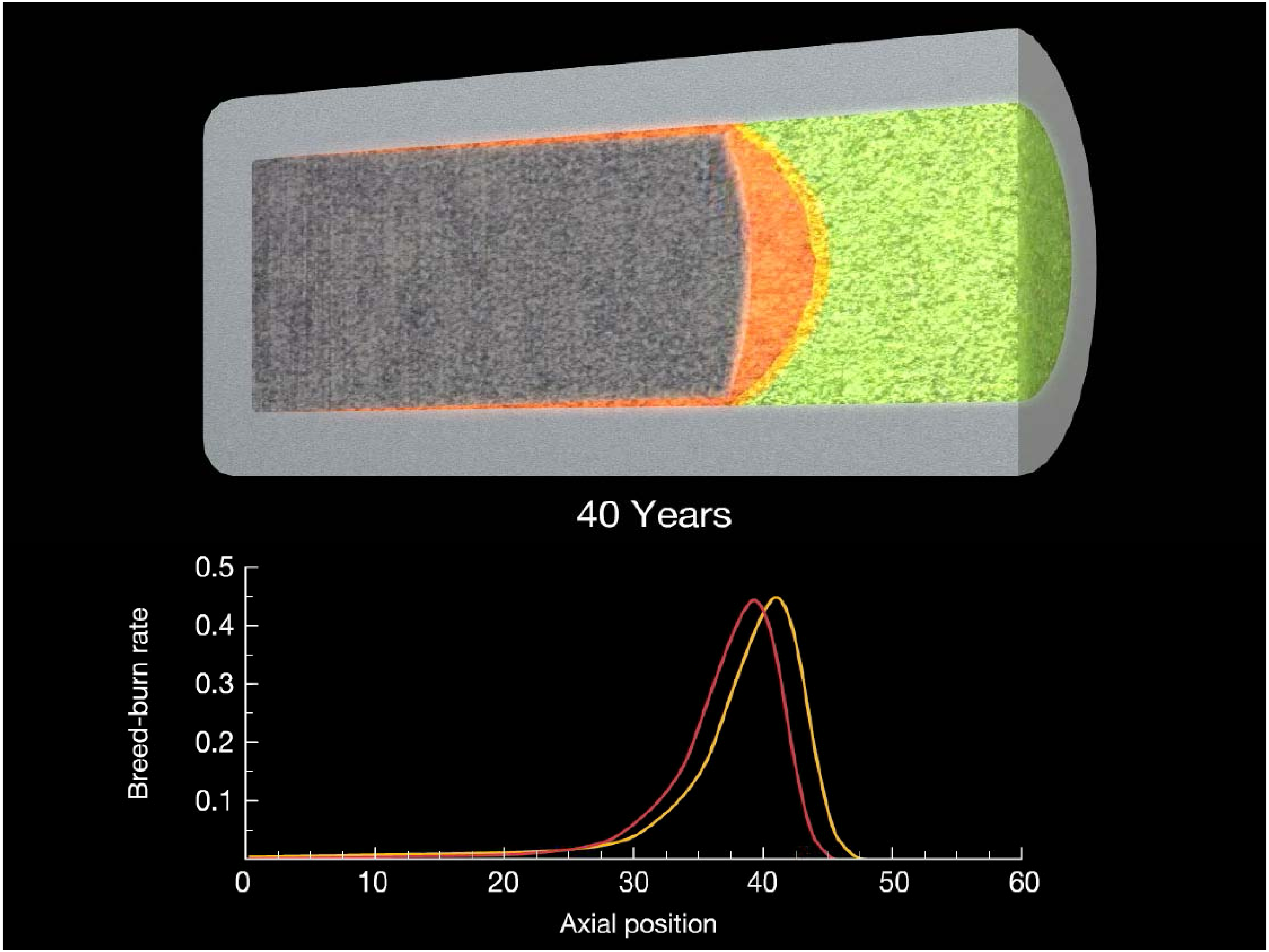
Burning wave
3 Years
Breeding wave
0.5
0.4
0.3
0.2
0.1
Breed-burn rate
0
10
20
30
40
50
60
Axial position

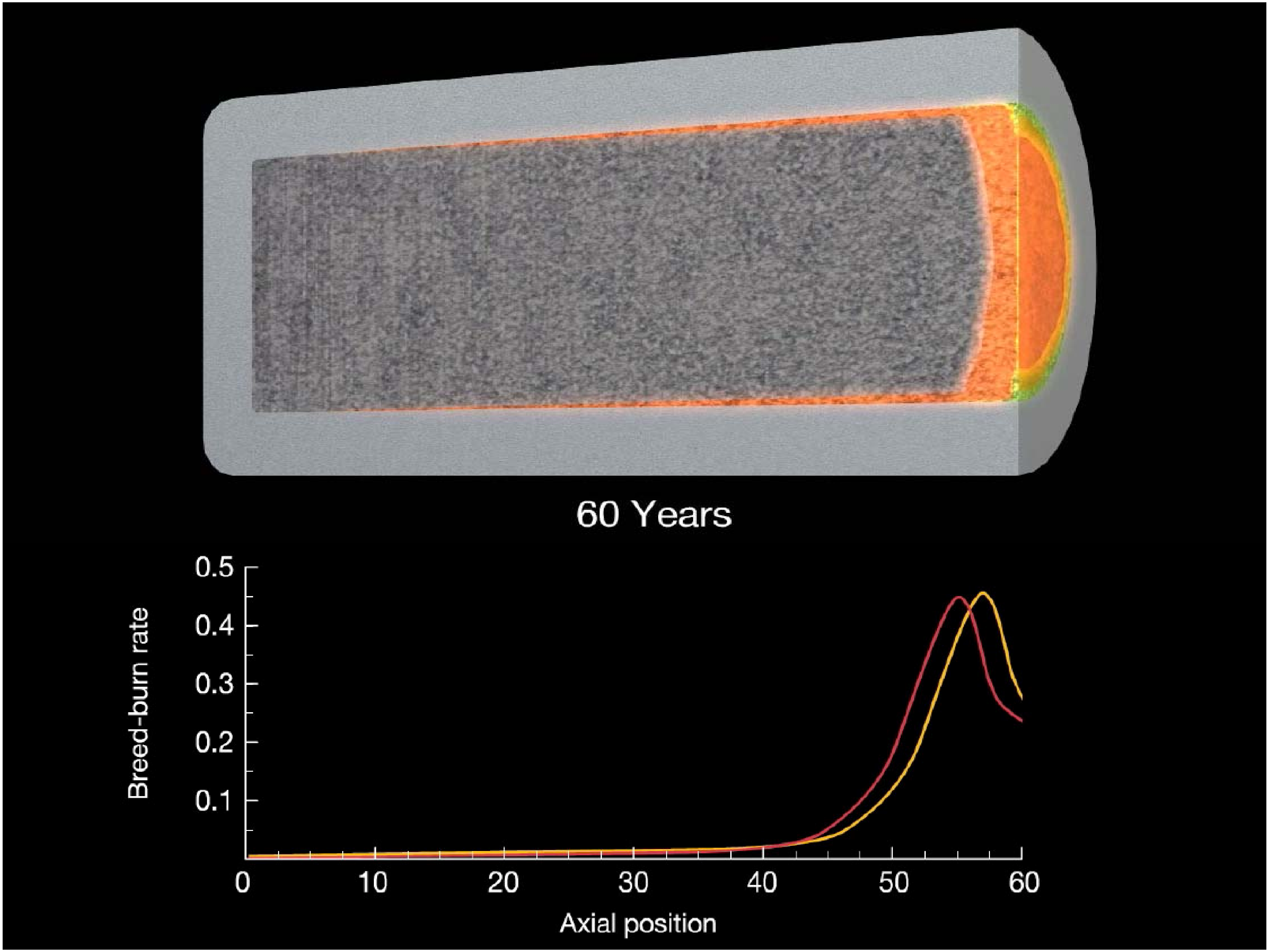


5 Years



At steady state, active core power density is similar to conventional FR


40 Years
Breed-burn rate
0.5
0.4
0.3
0.2
0.1
0
10
20
30
40
50
60
Axial position


60 Years
Breed-burn rate
0.5
0.4
0.3
0.2
0.1
0
10
20
30
40
50
60
Axial position

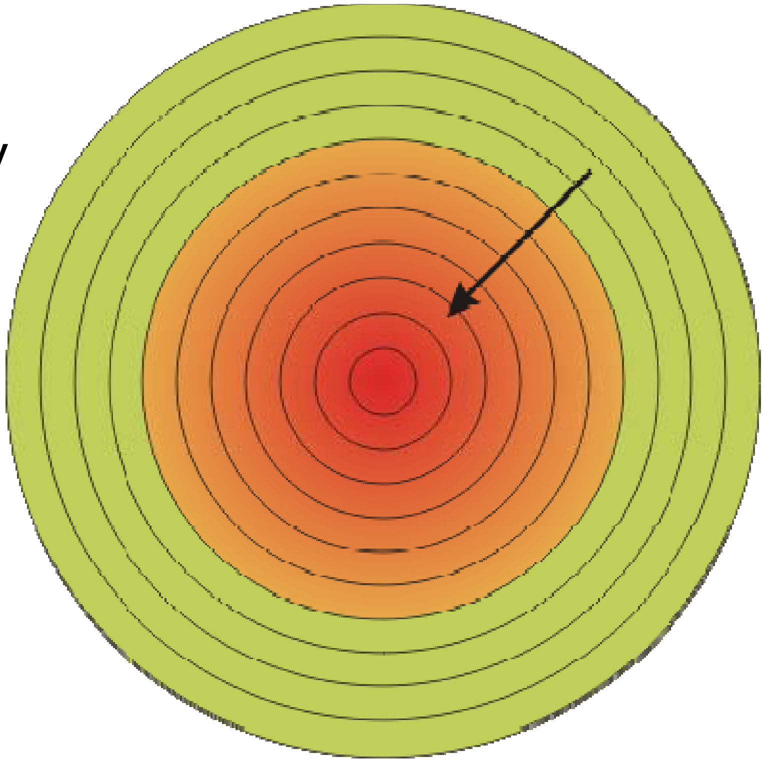
The Cylindrical Standing Wave Reactor

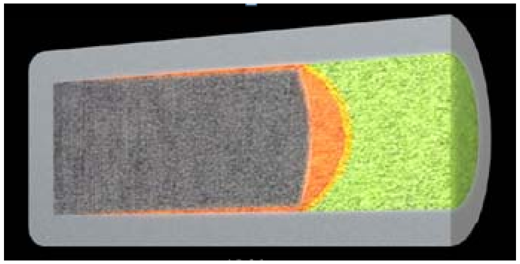
A Change of Geometry

- The burning region remains stationary
- Fresh fuel is moved into the wave
- Exhausted fuel is removed

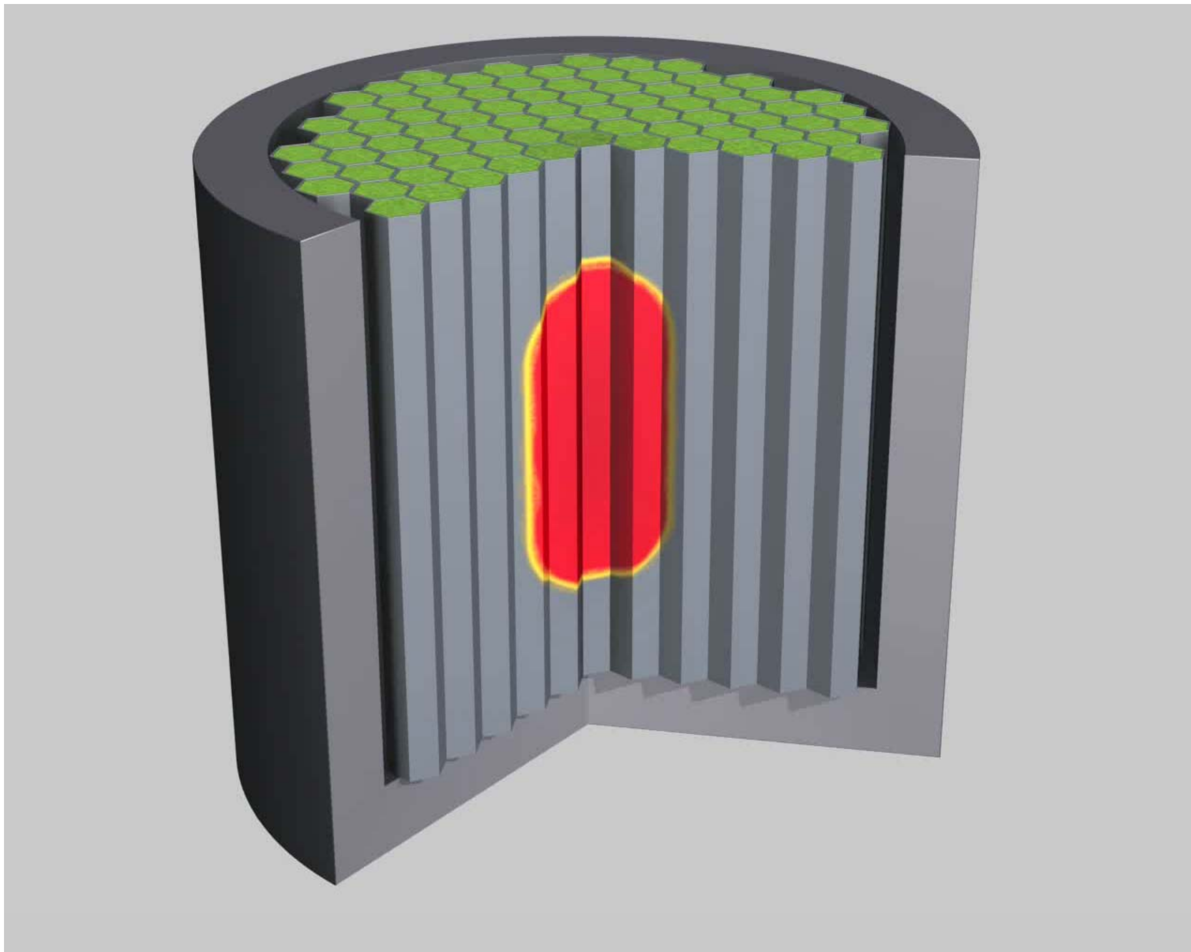
Advantages

- Neutrons cannot leak into exhausted fuel.
- The region to be cooled does not move.





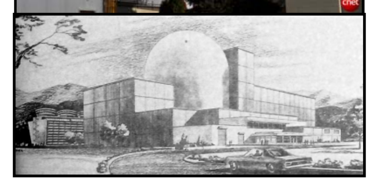
Cylindrical Standing Wave Reactor Fuel Movement



Profile of TerraPower

- Expert staff with 500 person-years of experience on real fast reactors (e.g., FFTF, EBR –I and EBR –II, Clinch River)
- Over 80 contracts with national labs, universities, companies, and expert consultants since 2007
- State-of-the-art computer capabilities and proprietary software to support detailed core performance simulations
- Access to data and fast reactor experience around the world



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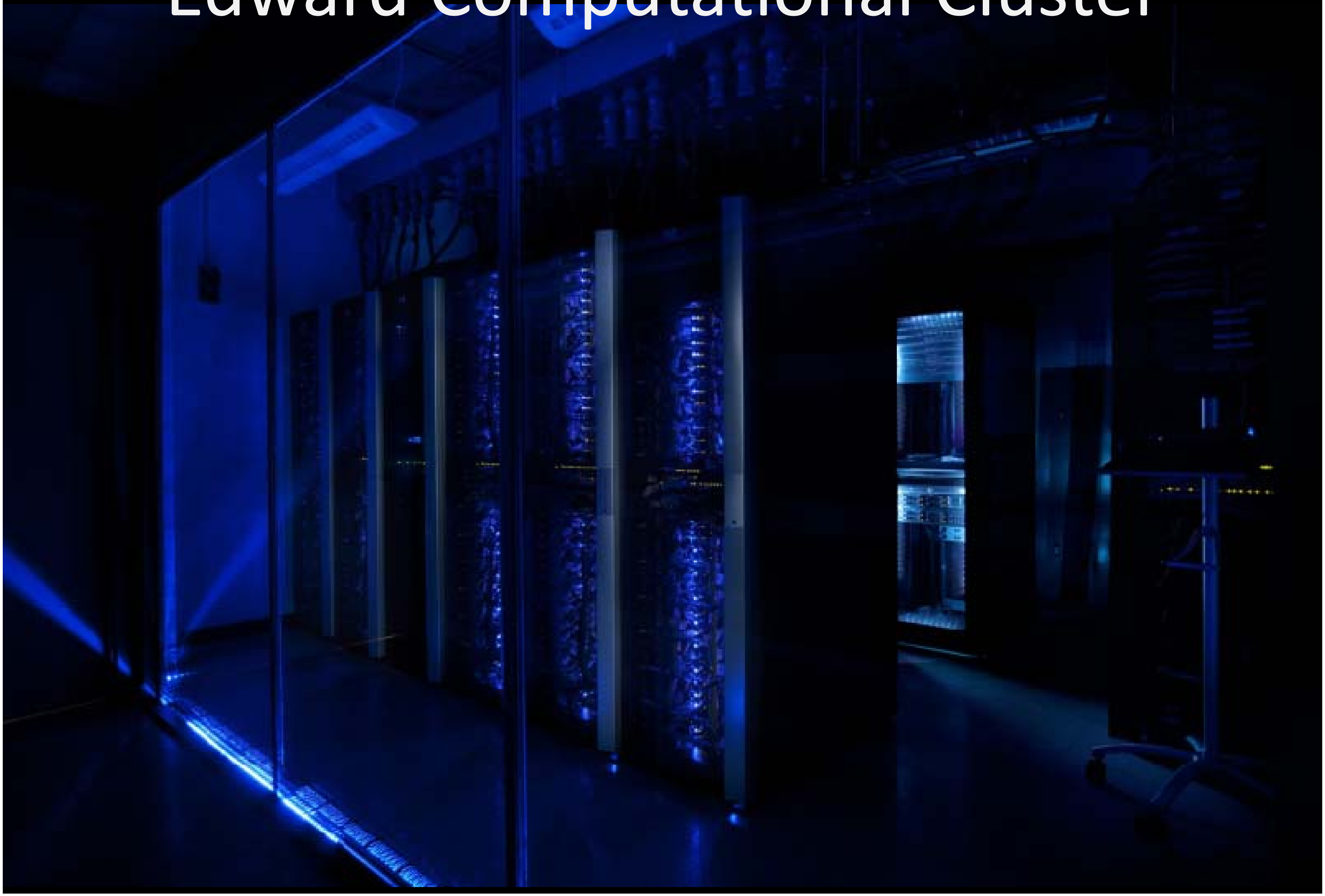
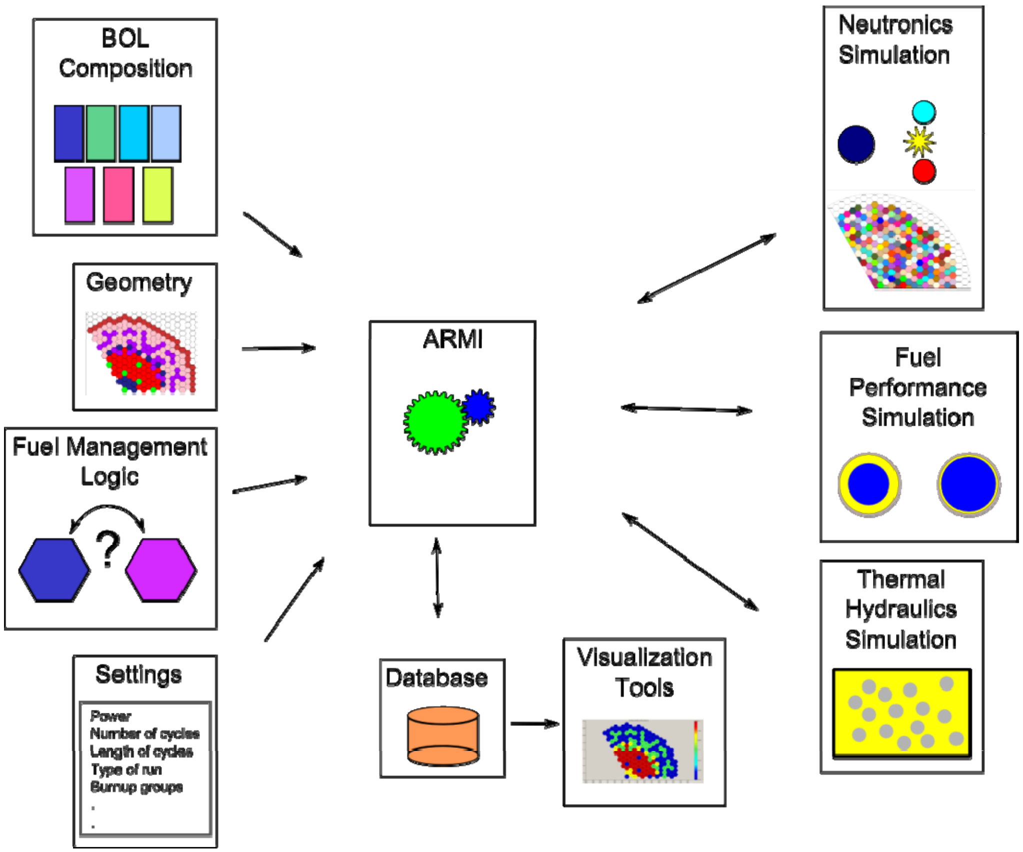
The TerraPower Extended Team

Methods Development	Materials & Fuel Development	Equipment & Process	Fuel Fabrication	Design
Argonne National Laboratory	INL Idaho National Laboratory	Curtiss Wright	KOBELCO KOBE STEEL GROUP	The Cameron Group
Berkeley University of California	Y-12 National Security Complex	GE Energy	NFS Nuclear Fuel Services, Inc.	Burns and Roe
Massachusetts Institute of Technology	UNLV University of Nevada Las Vegas		ROSATOM	M&D Professional Services Incorporated
	Los Alamos National Laboratory Est. 1943	Brayton Energy LLC		CBCG
	Texas A&M University	CCS, LLC		
	ВНИИНМ имени А.А. Бочвара			
	НИИАР			

Edward Computational Cluster



Advanced Reactor Modeling Interface

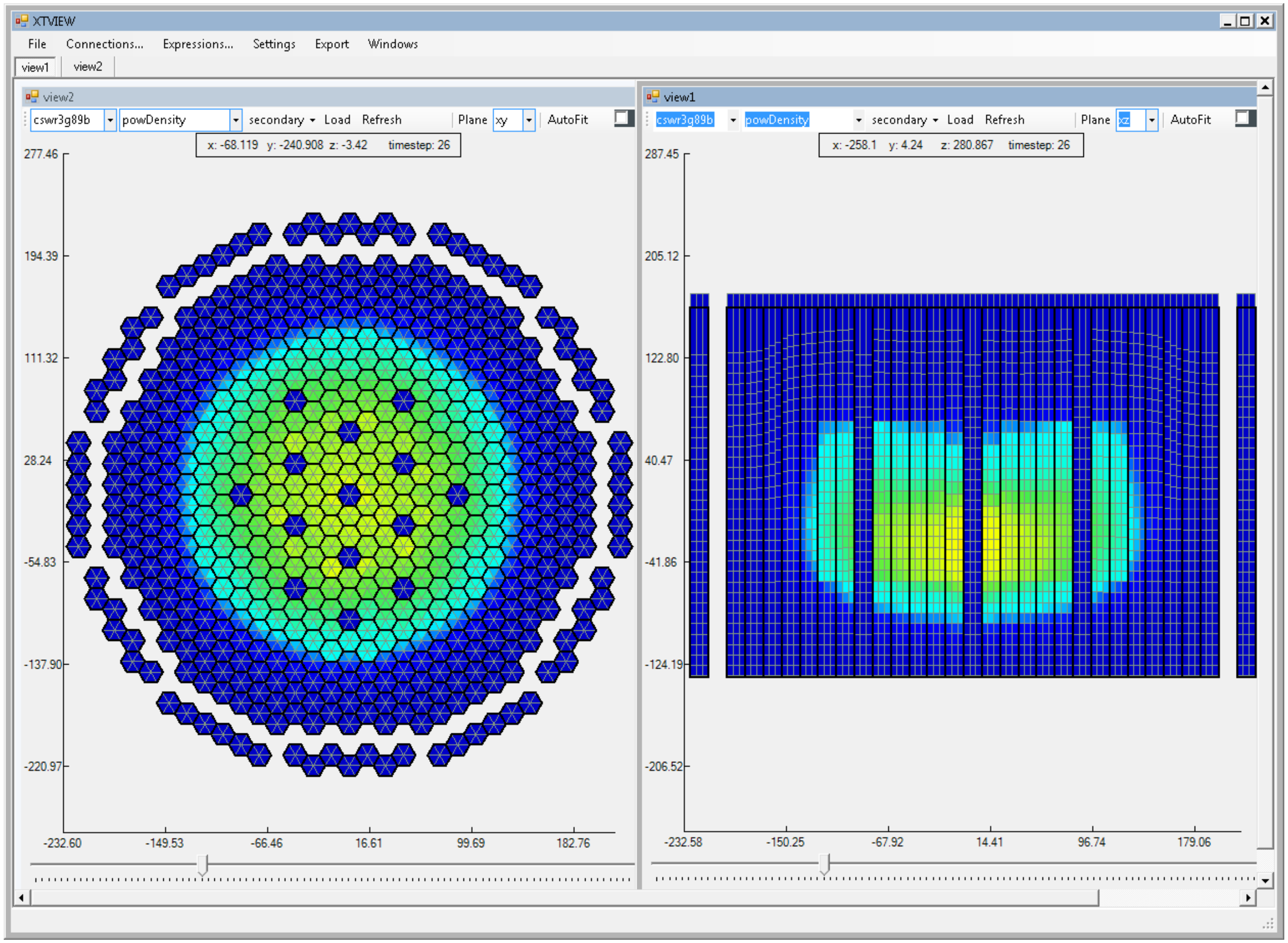


Software:

- MC**2
- REBUS/DIF3D
- MCNPXT/CINDER
- SUPERENERGY
- ANSYS
- FEAST/ALCHEMY
- XTVIEW
- SAS4A/SASSYS-1
- ARMI

Will run Monte Carlo simulations of 110,000 zones, each with 3400 nuclides, out for 60 years, and receive results in 1 day.

XTVIEW Screenshot



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Pragmatic Business Approach

- Can the TWR be as economic as existing LWRs?
  - TerraPower Reactor Plant (TPRP)
    - 1150 MW_e, 43 year core life, no refueling
    - Conceptual design complete November 2009
    - Total all in plant cost comparable to Gen III, III+ LWR
- What does the first TWR look like?
  - TerraPower – 1 (TP-1)
    - 500 MW_e first-of-a-kind, multi-mission demonstration reactor
    - Conceptual design complete November 2010
    - Supports immediate commercialization

TP-1 Missions

- TWR demonstration plant:
  - First electricity producing TWR – Startup about 2020
  - Confirms "standing wave" design, verifies shuffling strategies
  - Demonstrates key plant equipment and verifies that models agree with operational performance
  - Provides bases for 500 & 1150 MW_e TWR plants
  - Last step of fuel and material qualification
- Design features included for additional testing & development
  - Accommodates lead test fuel assemblies
  - Refueling capability for post irradiation fuel examinations
  - First-of-a-kind instrumentation, maintenance considerations

TP-1 Design Parameters

Power Level	1200 MW_{th} / 500 MW_e
Operating Temperatures	360°C / 510°C
Availability	90% average over 5 yr period
Minimum Lifetime	40 years
Fuel Type	U-Zr alloy in HT-9 clad
Primary Pumps	Mechanical (2)

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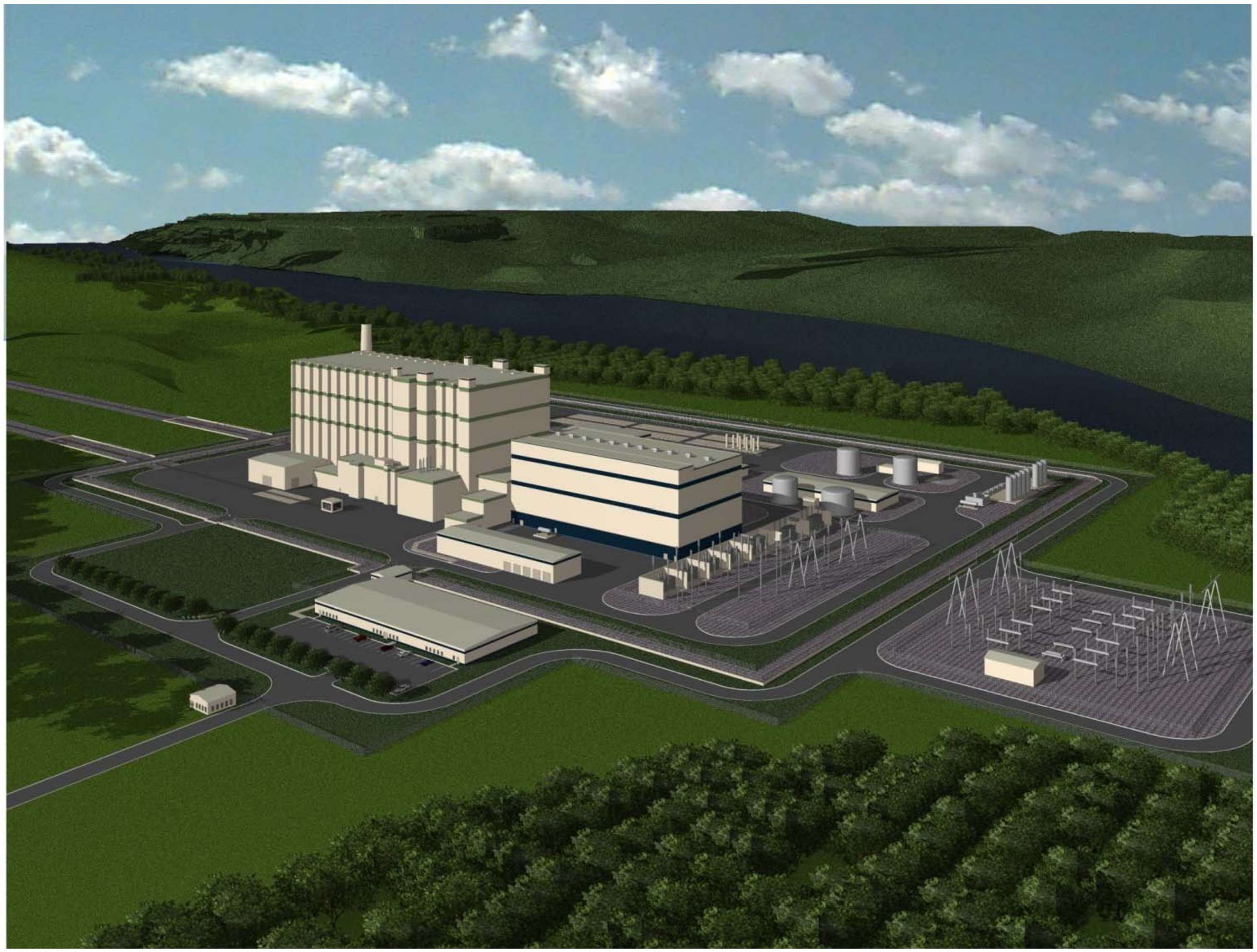
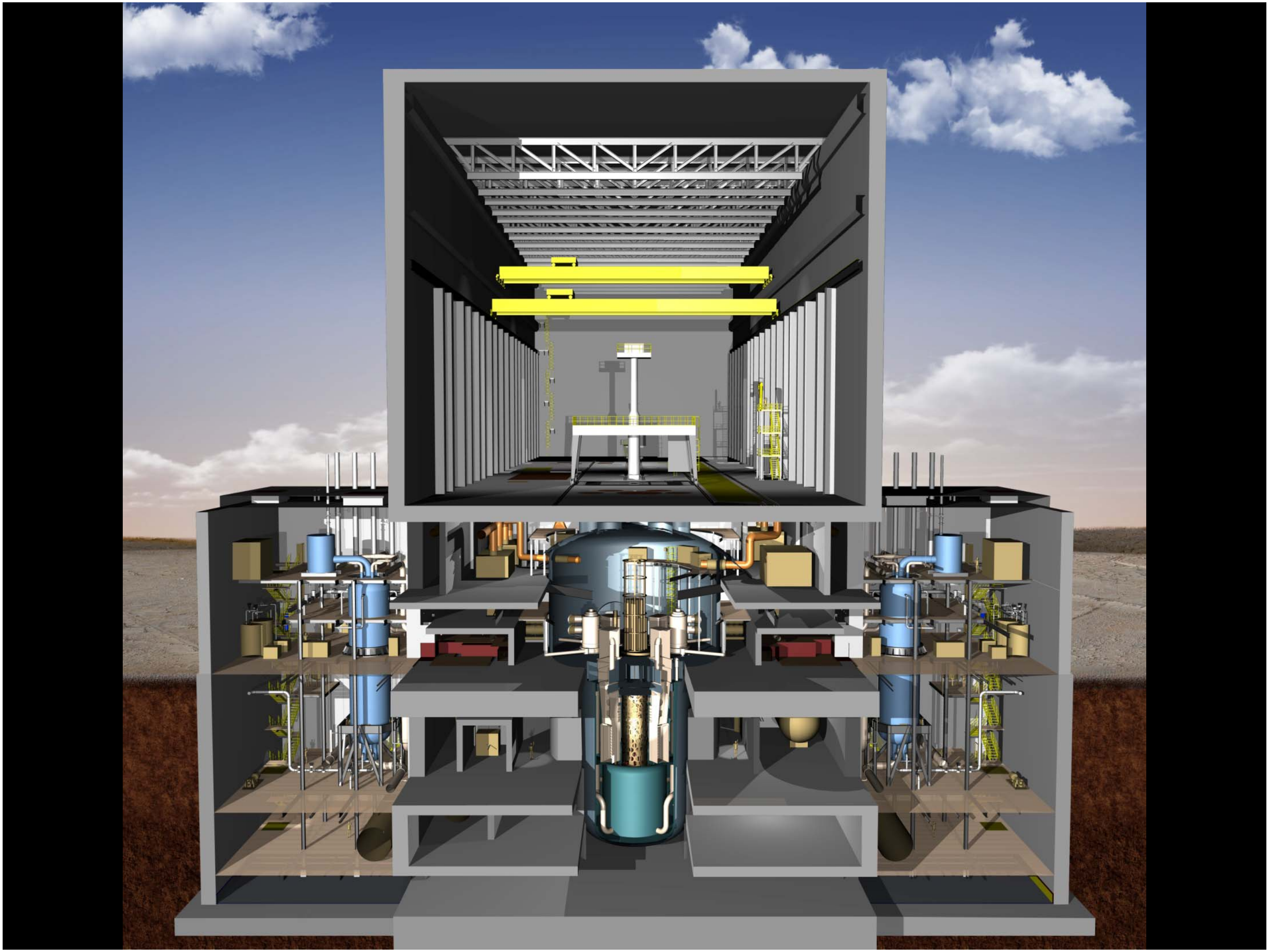
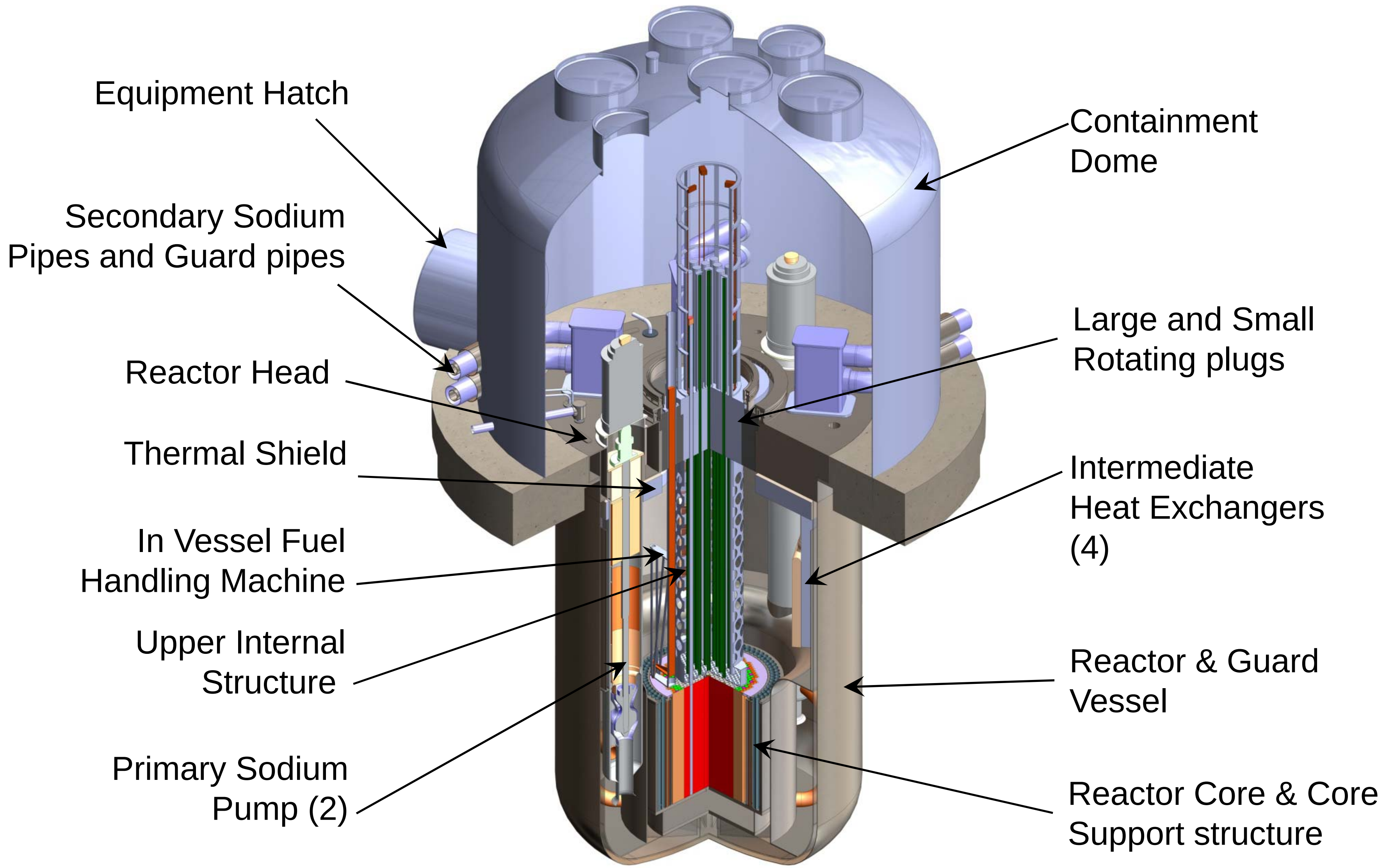
TP-1 Plant Rendering





TP1 Nuclear Island



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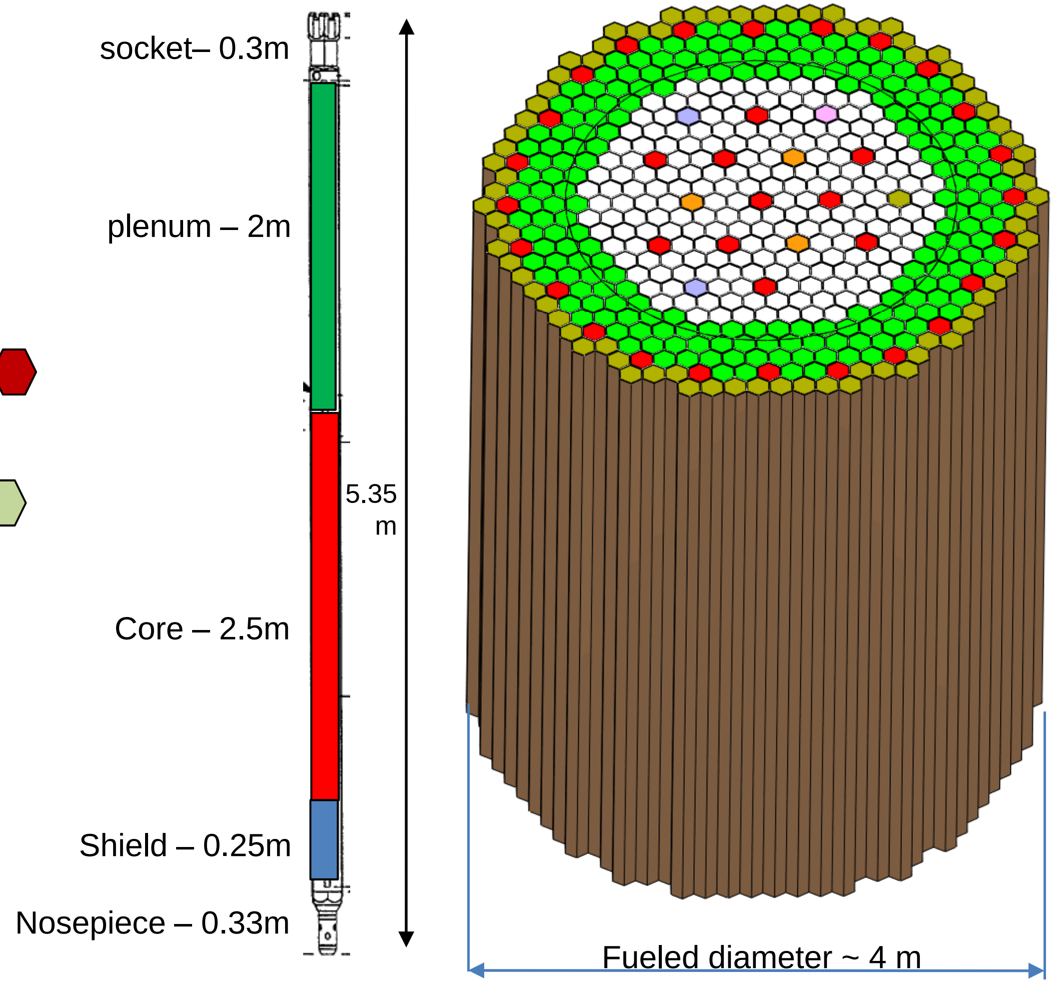
TP-1 Core Layout

- 189 starter FAs
- 210 feed (DU) FAs
- 10 control rods
- 3 diverse safety rods
- 24 fixed control assemblies (movable, no drives)
- 3 open test assemblies (fuel and material testing)
- Fuel supports core life of 47 yrs at average burnup 16%
- Metallic fuel (U-5%Zr)
- Pins are vented to coolant in a controlled manner



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Fuel and Materials Development

- High burnup metal fuel
  - ~30% peak for TWR
  - Data limit is 20% (in EBR-II)

- High neutron dose
  - ~500 dpa peak for TWR
  - Data limit is 200 dpa (in FFTF)

Safety Comparison LWR to TWR

Light Water Reactors

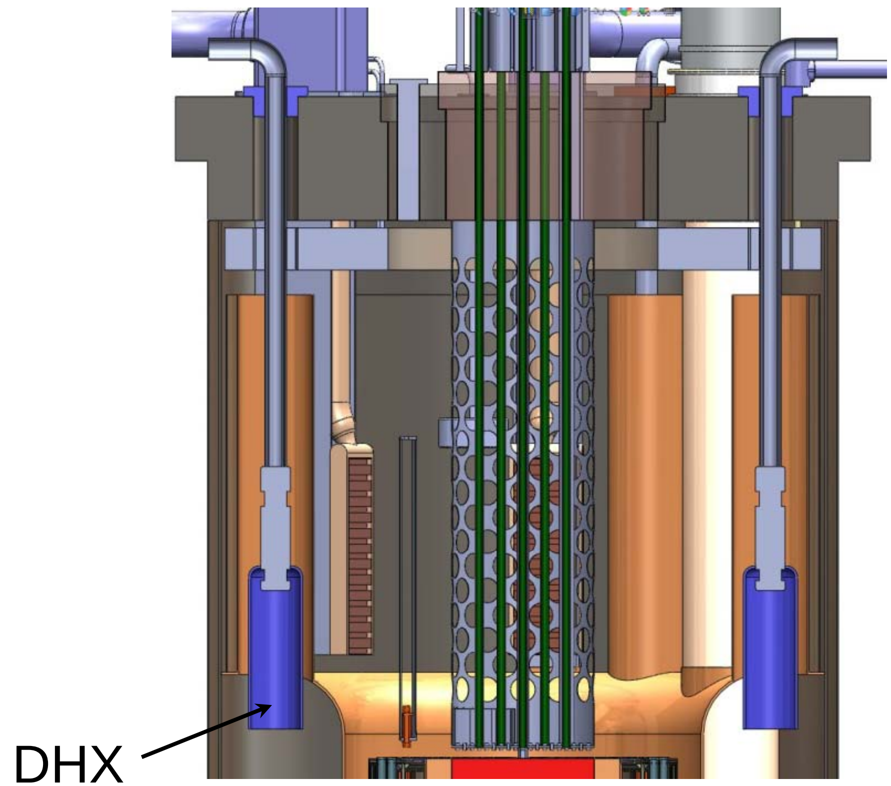
- Coolant water at high pressure
  - Loss of coolant credible
- Loop reactor: low thermal inertia
  - Decay heat to boil coolant: <2 hours for PWR, BWR is already at boiling point
- Relies on Diesels for backup power to remove decay heat
  - Diesels vulnerable to tsunami damage
- Zr-H_2O reaction generates H_2

Traveling Wave Reactor

- Coolant sodium at low pressure
  - Loss of coolant not credible
- Pool reactor: high thermal inertia
  - Decay heat to boil coolant: 25 hours – much more time to recover
- Relies on natural air circulation to remove decay heat
  - No need for electricity indefinitely
- No H_2 generation

Direct Reactor Auxiliary Cooling System

- DRACS is a completely passive, natural convection NaK heat transport loop that transfers heat from primary coolant to ambient air
  - Two heat exchangers in each loop
    - Na-to-NaK, in sodium pool
    - NaK-to-Air, in air stack
  - Four loops employed for redundancy



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Summary

TWR technology can lead to a sustainable, scalable reactor infrastructure that does not need enrichment or chemical reprocessing

- Only input fuel is depleted/natural uranium: tremendous energy security
- Large fuel cycle cost savings: much lower uranium requirements than LWR infrastructure
- Enables future phase-out of enrichment and reprocessing capability: the two avenues for proliferation

Questions?

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Backup

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Comparison of PWR and SFR Safety Considerations

Pressurized Water Reactors

- Loss of primary coolant accident credible
- Coolant has low boiling point
- 80 full power seconds to boil coolant at 1 atm
- <2 hours for decay heat to boil coolant at 1 atm
- Corrosive borated water coolant

Sodium Fast Reactors

- Loss of primary coolant accident not credible
- Coolant has high boiling point
- 680 full power seconds to boil coolant at 1 atm
- 25 hours for decay heat to boil coolant at 1 atm
- Corrosion inhibiting sodium coolant

Comparison of PWR and SFR Safety Considerations

Pressurized Water Reactors

- pressure gradient drives primary coolant into secondary (BOP) coolant
- steam generator is part of primary coolant boundary
- no intermediate barrier between primary & secondary coolant

Sodium Fast Reactors

- pressure gradient drives intermediate coolant into primary coolant
- steam generator <u>is not</u> part of the primary coolant boundary
- <u>has an intermediate coolant barrier</u> between primary & secondary coolant

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TWR has a Long Intellectual History

Year	Who	Work
1958	Saveli M. Feinberg	Unenriched fuel concept
1979	Michael J. Driscoll	Breed-burn concepts
1996	Edward Teller, Lowell Wood	Breed-burn waves
2000	Hugo van Dam	Formal analysis of fission waves
Early 2000s	Hiroshi Sekimoto	Analysis of CANDLE
2006–2011	TerraPower:	Extensive physics and engineering work on TWR